WE CLAIM:

1. A micro-transducer comprising:

a first membrane;

a second membrane comprising a first electrode, a second electrode, and a piezoelectric member disposed therebetween;

a fluid-tight cavity cooperatively formed between the first and second membranes; and

a working fluid disposed in the cavity.

2. The micro-transducer of claim 1, further comprising a low-temperature heat sink disposed adjacent the first membrane and a high-temperature heat source disposed adjacent the second membrane such that the transducer is operative as a micro-heat engine having a thermodynamic cycle, wherein thermal energy, flowing from the high-temperature heat source to the low-temperature heat sink through the micro-heat engine during the thermodynamic cycle, is converted into electrical energy.

3. The micro-transducer of claim 2, wherein the low-temperature heat sink has at least one thermal switch positioned to thermally couple the low-temperature heat sink and the first membrane at least once during the thermodynamic cycle of the micro-heat engine and the high-temperature heat source has at least one thermal switch positioned to thermally couple the high-temperature heat source and the second membrane at least once during the thermodynamic cycle of the micro-heat engine.

4. The micro-transducer of claim 1, further comprising a low-temperature heat source disposed adjacent the second membrane and a high-temperature heat sink disposed adjacent the first membrane such that the transducer is operative as a micro-heat pump having a thermodynamic cycle, wherein electrical energy is consumed to transfer heat from the low-temperature heat source to the high-temperature heat sink.

5. The micro-transducer of claim 4, wherein the low-temperature heat source has at least one thermal switch positioned to thermally couple the low-temperature heat source and

the second membrane at least once during the thermodynamic cycle of the micro-heat pump, and the high-temperature heat sink has at least one thermal switch positioned to thermally couple the high-temperature heat sink and the first membrane at least once during the thermodynamic cycle of the micro-heat pump.

6. The micro-transducer of claim 1, wherein the working fluid is a saturated mixture of vapor and liquid.

7. The micro-transducer of claim 1, wherein the first membrane comprises a layer of silicon, and the second membrane comprises a layer of silicon for supporting the first and second electrodes and the piezoelectric member.

8. A micro-transducer comprising:

a first layer;

a second layer having piezoelectric properties and joined to the first layer so as to form a fluid-tight cavity therebetween; and

a working fluid contained within the cavity;

wherein thermal energy flowing into the micro-transducer causes the working fluid to expand, thereby distending the second layer for generating an electrical charge.

9. The micro-transducer of claim 8, wherein the first layer comprises a first substrate forming a first membrane, and the second layer comprises a second substrate forming a second membrane, the micro-transducer further comprising an intermediate layer between the first and second layers and defining a recess, the first membrane, the second membrane and the recess together defining the fluid-tight cavity.

10. The micro-transducer of claim 8, wherein the working fluid is at least a vapor phase.

11. The micro-transducer of claim 8, further comprising a high-temperature heat source positioned to transfer heat energy into the micro-transducer.

12. The micro-transducer of claim 11, wherein the high-temperature heat source is positioned to thermally conduct heat energy into the micro-transducer.

13. The micro-transducer of claim 8, further comprising a low-temperature heat sink positioned to receive heat energy from the micro-transducer.

14. The micro-transducer of claim 13, wherein the low-temperature heat sink is positioned to receive heat energy from the micro-transducer through conduction.

15. The micro-transducer of claim 8, wherein the first layer is more rigid than the second layer so that the second layer distends outwardly and the first layer retains a substantially constant profile whenever heat energy flows into the micro-transducer to expand the working fluid.

16. A structure having a plurality of micro-transducers, the structure comprising:

a first major layer;

a second major layer juxtaposed to the first layer;

a plurality of fluid-tight cavities cooperatively formed between the first and second major layers;

a working fluid contained in the cavities;

a plurality of first electrodes carried by the first major layer at each of said cavities;

a plurality of piezoelectric members carried by the first electrodes at each of said cavities; and

a plurality of second electrodes carried by the piezoelectric members at each of said cavities.

17. The structure of claim 16, wherein each of the first electrodes comprises a unitary first metallic layer overlaying the first surface, the plurality of piezoelectric members comprising a unitary piezoelectric layer overlaying the first metallic layer, and the plurality of second electrodes comprising a unitary second metallic layer overlaying the piezoelectric layer.

18. The structure of claim 16, wherein the first major layer comprises a first substrate and the second major layer comprises a second substrate, the first substrate having a plurality of recessed portions defining first membranes of the micro-transducers, the second substrate having a plurality of recessed portions aligned with the recessed portions of the first substrate and defining second membranes of the micro-transducers.

19. The structure of claim 16, further comprising an intermediate layer disposed between the first and second major layers, the intermediate layer defining a plurality of recesses that define respective cavities between the first and second major layers.

20. The structure of claim 19, wherein the intermediate layer comprises a photo-resist material.

21. The structure of claim 16, wherein the working fluid is a saturated mixture of vapor and liquid.

22. A method for constructing a micro-transducer, the method comprising:

(a) providing a first substrate and a second substrate;

(b) adding a first metallic layer, a piezoelectric layer, and a second metallic layer to the first substrate;

(c) forming a cavity between the first substrate and the second substrate;

(d) introducing a working fluid into the cavity; and

(e) joining together the first substrate and the second substrate so as to seal the fluid in the cavity.

23. The method of claim 22, wherein step (c) comprises providing an intermediate layer and removing a portion of the intermediate layer to form a cavity, and step (e) comprises joining together the first substrate, the intermediate layer, and the second substrate so as to seal the fluid in the cavity.

24. The method of claim 22, wherein step (c) comprises removing a portion of at least one of the first substrate or the second substrate to form a cavity.

25. The method of claim 23, further comprising removing a portion of the first substrate to form a first membrane, removing a portion of the second substrate to form a second membrane, adding a first metallic layer, a piezoelectric layer, and a second metallic layer to the first membrane, and joining together the first substrate, the intermediate layer and the second substrate so as to seal the fluid in the cavity between the first and second membranes.

26. The method of claim 22, wherein the first and second substrates comprise respective silicon wafers.

27. The method of claim 22, further comprising etching away a portion of the first substrate to form a first membrane, etching away a portion of the second substrate to form a second membrane, adding a first metallic layer, a piezoelectric layer, and a second metallic layer to the first membrane, and joining together the first substrate and the second substrate so as to seal the fluid in the cavity between the first and second membranes.

28. The method of claim 22, wherein the working fluid comprises vapor and liquid.

29. A method for constructing a plurality micro-transducers, the method comprising:

providing a first substrate and a second substrate;

forming a plurality of generator members on the first substrate, each generator member comprising a first electrode, a piezoelectric layer, and a second electrode;

forming a plurality of cavities between the first and second substrates;

introducing a working fluid into the cavities; and

joining together the first substrate and the second substrate so as to seal the fluid in the cavity between the first and second membranes.

30. The method of claim 29, further comprising separating the micro-transducers from the first and second substrates to provide individual micro-transducers.

31. The method of claim 29, wherein the step of forming a plurality of cavities between the first and second substrates comprises the steps of providing an intermediate layer and removing portions of the intermediate layer to form a plurality of cavities, and wherein the first substrate, the intermediate layer, and the second substrate are joined together to form a plurality of micro-transducers.

32. The method of claim 29, further comprising the steps of removing portions of the first substrate to form a plurality of first membranes, removing portions of the second substrate to form a plurality of second membranes, and positioning the generator members on the first membranes.

33. The method of claim 32, wherein the step of forming a plurality of cavities between the first and second substrates comprises providing an intermediate layer and removing portions of the intermediate layer to form a plurality of cavities, the method further comprising the steps of joining together the first substrate, the intermediate layer, and the second substrate to form a plurality of micro-transducers each comprising a first membrane, a second membrane, a cavity between the first and second membranes, and a fluid disposed in the cavity.

34. A method of generating electrical energy with a micro-transducer having a chamber for a fluid, wherein a surface of the chamber comprises a piezoelectric generator, the method comprising:

introducing a fluid into the chamber; and

expanding the fluid to cause the piezoelectric generator to distend outwardly from the chamber, thereby causing the piezoelectric generator to generate electrical energy.

35. The method of claim 34, wherein the fluid is sealed in the chamber, and heat energy is flowed through the micro-transducer between a high-temperature heat sink and a low-temperature heat sink to cause the fluid to expand.

36. The method of claim 35, further comprising the steps of transferring heat into the micro-transducer from the high-temperature heat sink through conduction, and transferring heat from the micro-transducer to the low-temperature heat sink through conduction.

37. The method of claim 35, wherein (a) the piezoelectric generator is deflectable between an outwardly deflected position and an inwardly deflected position, (b) heat flowing into the micro-transducer causes the piezoelectric generator to deflect to the outwardly deflected position, and (c) heat flowing out of the micro-transducer causes the piezoelectric generator to deflect to the inwardly deflected position.

38. The method of claim 37, wherein electrical energy is removed from the piezoelectric generator at the outwardly deflected position, the inwardly deflected position, and at a neutral, non-deflected position intermediate the outwardly deflected position and the inwardly deflected position.

39. The method of claim 34, wherein the fluid comprises a fuel, the method further comprising introducing a first mixture of the fuel and an oxidizer into the chamber, wherein expanding the fluid comprises combusting the first mixture of the fuel and the oxidizer to distend the piezoelectric generator.

40. The method of claim 39, further comprising introducing a second mixture of the fuel and the oxidizer into the chamber and combusting the second mixture of the fuel and the oxidizer.

41. A micro-transducer comprising:

a support structure;

a piezoelectric generator coupled to the support structure and being deflectable relative to the support structure; and

a mass carried by the piezoelectric generator at a position to decrease the resonant mechanical frequency of the piezoelectric generator;

wherein deflection of the piezoelectric generator relative to the support structure causes the piezoelectric generator to generate an electric charge.

42. The micro-transducer of claim 41, wherein the support structure is carried by a body that oscillates at a predetermined frequency approximately equal to a resonant mechanical frequency of the piezoelectric generator so that oscillation of the body causes the piezoelectric generator to deflect approximately at its resonant mechanical frequency.

43. The micro-transducer of claim 41, wherein the piezoelectric generator comprises a cantilever having a first, supported end coupled to the support structure and a second, free end opposite the first end, and wherein the mass is positioned proximate the second end of the piezoelectric generator.

44. The micro-transducer of claim 41, wherein the piezoelectric generator comprises a flexible membrane having first and second ends coupled to the support structure and a deflectable portion extending between the first and second ends, and wherein the mass is carried by the deflectable portion at a position about half way between the first and second ends.

45. The micro-transducer of claim 41, wherein the piezoelectric generator comprises first and second electrodes, a piezoelectric material disposed between the first and second electrodes, and a support layer for supporting the first and second electrodes and the piezoelectric material.

46. The micro-transducer of claim 45, wherein the thickness of the support layer is less than the thickness of the piezoelectric material.

47. The micro-transducer of claim 41, wherein the resonant mechanical frequency of the piezoelectric mechanism is between about 1 and 1000 Hz.

48. A method of converting kinetic energy to electrical energy with a piezoelectric generator, the method comprising:

coupling the piezoelectric generator to an oscillable body so that the piezoelectric generator is movable relative to the body, wherein the oscillations of the body causes the piezoelectric generator to oscillate, and thus generate an electric charge; and

conduct the electric charge from the piezoelectric generator.

49. The method of claim 48, wherein the body oscillates at a predetermined frequency, and the piezoelectric generator is configured to have a resonant mechanical frequency approximately equal to the frequency of oscillation of the body to maximize electrical energy generated by the piezoelectric generator.

50. The method of claim 48, wherein the oscillating body is a vibrating body.

51. The method of claim 48, further comprising powering an electrical device with the electric charge.

52. The method of claim 48, further comprising directing the electric charge to a battery so as to recharge the battery.

53. The method of claim 49, further comprising placing a mass on the piezoelectric generator to match the mechanical resonant frequency of the piezoelectric generator with the frequency of oscillation of the body.

54. A piezoelectric apparatus for generating electrical energy, comprising:

a first substrate;

a plurality of cantilevers formed in the first substrate; and

a respective piezoelectric unit disposed on each cantilever.

55. The apparatus of claim 54, further comprising a second substrate having a plurality of cantilevers formed therein, and a respective piezoelectric unit disposed on each cantilever, the second substrate being stacked superposedly with respect to the first substrate.

56. The apparatus of claim 54, further comprising at least one flow channel defined between the first substrate and the second substrate for receiving a pressurized fluid.

57. The apparatus of claim 56, wherein the cantilevers of the first substrate are curved toward the second substrate and the cantilevers of the second substrate are curved toward the first substrate.

58. The apparatus of claim 54, wherein the first substrate comprises a monolithic body, and the cantilevers comprise recessed portions of the first substrate that are connected at one end to the first substrate.

59. An apparatus for generating an electric current, comprising:

a support structure;

a piezoelectric generator coupled to the support structure and being deflectable relative to the support structure; and

a fluid that, when flowing under pressure, causes the piezoelectric generator to deflect and thus, generate an electric charge.

60. The apparatus of claim 59, wherein the piezoelectric generator is pre-stressed to cause the piezoelectric generator to be curved.

61. The apparatus of claim 59, wherein the piezoelectric generator has a first end coupled to the support and a second, free end opposite the first end, the apparatus further comprising a fluid channel defining a flow path for the fluid, wherein the second end of the piezoelectric generator is positioned in the flow path and configured to oscillate between a first position and a second position to open and close, respectively, the fluid channel whenever the fluid is flowing under pressure.

62. The apparatus of claim 59, wherein the fluid is pulsed to cause the deflectable portion to oscillate between a first position and a second position.

63. The apparatus of claim 62, wherein the fluid is pulsed at a frequency equal to the resonant mechanical frequency of the piezoelectric generator.

64. The apparatus of claim 59, wherein the fluid comprises a superheated vapor.

65. A piezoelectric micro-transducer comprising:

a support member defining a plane; and

a cantilevered piezoelectric unit having a first end and an opposing second end, the first end coupled to the support member, the second end being deflectable relative to the support member, and the piezoelectric unit being pre-stressed so that it is curved away from the plane of the support member.

66. The micro-transducer of claim 65, wherein the piezoelectric unit has a pre-stressed layer.

67. The micro-transducer of claim 66, wherein the pre-stressed layer comprises a layer of piezoelectric material.

68. The micro-transducer of claim 66, wherein the pre-stressed layer comprises a metallic layer.

69. The micro-transducer of claim 66, wherein the pre-stressed layer is applied in compression to the piezoelectric unit.

70. The micro-transducer of claim 66, wherein the pre-stressed layer is applied in tension to the piezoelectric unit.

71. The micro-transducer of claim 65, further comprising a fluid that, when flowing under pressure, causes the second end of the piezoelectric unit to deflect from a first position to a second position to generate an electric charge.

72. An assembly for generating electrical power, comprising:

a source of a pressurized working fluid/fuel;

a boiler for heating the working fluid/fuel, the working fluid/fuel also serving as the fuel for the boiler;

a first piezoelectric generator positioned downstream of the boiler and configured to generate an electric charge when deflected by working fluid/fuel flowing from the boiler; and

a combustor positioned downstream of the first piezoelectric generator and configured to burn working fluid/fuel flowing from the first piezoelectric generator for heating working fuel/fluid in the boiler.

73. The assembly of claim 72, further comprising a first superheater positioned downstream of the boiler and upstream of the first piezoelectric generator, the first superheater being configured to superheat working fluid/fuel flowing from the boiler.

74. The assembly of claim 72, further comprising a second superheater positioned downstream of the first piezoelectric generator for superheating working fluid/fuel flowing from the first piezoelectric generator, and a second piezoelectric generator positioned downstream of the second superheater, the second piezoelectric generator being configured to generate an electric current when deflected by the working fluid/fuel flowing from the second superheater.